GEOTECHNICAL STUDY ON BEHAVIOUR OF HIGH CONCENTRATED ASH SLURRY

A Thesis Submitted for Partial Fulfilment
of the Requirements for the degree of

Bachelor of Technology
In

Civil Engineering

By

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CERTIFICATE

This is to certify that project entitled "Geotechnical Study on Behaviour of High Concentrated Ash Slurry" submitted by Susovan Kumar Sahoo in partial fulfilment of the requirements for the award of Bachelor of Technology Degree in Civil Engineering at National Institute of Technology, Rourkela is an authentic work carried out by him under my personal supervision and guidance. To the best of my knowledge the matter embodied in this project review report has not been submitted in any college/institute for awarding degree or diploma.

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CONTENTS

ABSTRACT

Electric power generation in India has stepped up to numerous times in last decade and major portion of this power generation is coming from the coal based thermal plants. The chief by-product of thermal power plants are fly and bottom ashes. Transportation of ash slurry is a key problem in its efficient disposal. The foremost difficulty linked with ash slurry is that the particles settle down earlier than preferred. Lately, high concentrated slurry disposal (HCSD) structure has been hosted to get over of these problems. In this transportation system, ash slurry doesn’t only flow till it reaches the destination, but also settles down on the ash pond. This study describes the geotechnical properties of ash slurry of HCSD system in terms of densities, specific gravity, moisture content, and permeability. Change in properties of field tests with time are also shown in graphs. These studies and comparison with traditional mode of transportation will provide thorough understanding to the slurry disposal organization.

Key words: power generation, ash slurry, transportation system, HCSD, geotechnical properties

LIST OF FIGURES

LIST OF FIGURES

Chapter 1

1. INTRODUCTION

Electric power generation in our country steps up to numerous times in the last decade. The major portion of the power comes from coal based thermal power plants by combustion of coal. As an outcome vast amounts of ash are produced in thermal factories. Presently, India is yielding more than a hundred millions of tonnes of ash per year. Ash should be productively consumed and transported along with stockpiled in an environmentally secured manner. But only a very few percentage is utilized for various makings like brick, cement and road construction. The remaining major part is disposed to ash pond in slurry. Fly ash disposal is an actual ecological thoughtful issue now-a-days. Fly and bottom ash are integrated unitedly and transmitted hydraulically to ash ponds. Centrifugal pumps are used for transportation of ash slurry to ash ponds. Conventional ash slurry disposal system as lean concentration slurry disposal (LCSD) stances several key disadvantages. Lately, high concentration slurry disposal (HCSD) system is presented at some industries to get over those complications.

High concentration slurry disposal (HCSD) is a modern technique of disposing by-product fly ash formed from thermal power industries to ash pond. This disposal system has also some contributed advantages as comparison to conventional lean slurry disposal system. The behaviour of HCSD disposal system and contrast with LCSD system will facilitate a comprehensive intuition to thermal power factories. In this project, the laboratory and field study on geotechnical parameters of HCSD will be exercised, which will benefit in knowing the geotechnical aspects of the advantages.

1.1 TYPES OF ASH GENERATED FROM THERMAL POWER PLANTS

1.1.1 Bottom Ash:

Bottom ash is get compiled outside the hoppers at the foot of boilers in thermal power plants. They are generally in form of lumps which comprises traces of combustible materials entrenched in forming clinkers. Only 20-25% of total ash produced is bottom ash at plants.

1.1.2 Fly Ash:

Fly ash is residue produced in combustion, constitutes finer particles that rises with flue gases. So fly ash is also known as flue-ash. These are very finer spherical particles with maximum particle size of 300 µm. Fly ash is get collected by electrostatic precipitators (ESP). 75-80% of total ash produced at plant is fly ash.

1.2 METHODS OF ASH SLURRY TRANSPORTATION

There are basically two methods to perform it.

1. Lean Concentration Slurry Disposal (LCSD)

2. High Concentration Slurry Disposal (HCSD)

1.2.1 Lean Concentration Slurry Disposal (LCSD):

The ash concentration is about only 10-15% by weight of slurry. This method has been conventionally used for disposal of ash slurry in dilute form with the help of centrifugal pump, in which it requires vast magnitude of energy.

1.2.2 High Concentrated Slurry Disposal (HCSD):

The ash concentration is about 60-70% by weight of slurry by which it reduces the water consumption. This method is more efficient than the previous with less energy consumption. Reciprocating pumps, Progressive cavity pumps and Diaphragm pumps are generally used for transportation.

1.3 SIGNIFICANCE OF PRESENT STUDY

High concentration fly ash slurry disposal (HCSD) is a contemporary system of disposing ash acquired from thermal power plants as incurred by combustion. Aside, it has some contributed advantages over conventional lean concentration slurry disposal (LCSD) system. So this project will facilitate thorough understanding to thermal power industries by exploring geotechnical aspects or behaviour of HCSD system and comparing with LCSD system.

1.4 ORGANISATION OF THE THESIS

Following this introductory chapter (Chapter-1), the organisation of further chapters are completed as explained below.

Chapter-2 comprises the literature review for various studies conducted in past on this present study along with acute conclusions of their studies. It also contains the aim and scope of the existing study.

Chapter-3 explains detailed experimental procedures of different tests conducted for this study and states their formulae for calculation of different properties of ash.

Chapter-4 contains results obtained from numerous observations of different tests for determination of physical and chemical parameters of ash slurry. It also covers comparisons between different parameters of fly ash properties and their discussions.

Chapter-5 draws the conclusion of this present study and describes it briefly from grave discussions.

Chapter 2

2. REVIEW OF LITERATURE

The widespread domain of the methods of transportation of ash slurry in numerous arenas has paved the way for a large number of researches concerning ash slurry. It is highly essential to study geotechnical behaviour of high concentrated ash slurry in order to determine the efficient way of transportation of the slurry. The following paragraphs deliver different earlier works that have been done on this subject.

Usui H., Li L. and Suzuki H. (2001) proposed that maximum packing volume fraction for non-spherical suspension was effectively applied to forecast the slurry viscosity under completely dispersed circumstances. The model ensued in the estimation of inter particle bonding force within primary particles in a cluster, the power consumption and flow rate relationship in hydraulic slurry pipeline transportation system. A potential mode to diminish the overall cost of slurry pipeline system by means of periodic addition of stabilizer is proposed.

Verma A. K., Singh S.N. and Seshadri V. (2006) described that the pressure drop for any particular solid concentration upsurges with increase in velocity and at any given flow velocity pressure drop increases with rise in solid concentration and investigated that Specific Energy consumption decreases up to a concentration of 65% by weight and sharply rises past this value.

Naik H. K., Mishra M. K. and Rao K. U. M. (2011) suggested the fly ash slurry rheology is strongly inclined by chemical additives and the surface tension of the treated fly ash slurry is reduced as compared to untreated fly ash which indicates that fly ash has superior potential to be conveyed in pipelines with accession of cationic surfactant and a counter-ion which would decrease specific gravity consumption and water demand.

Kawaguchi et al. and Li et al. (2008) experimented with equivalent quantity of surfactant and counter-ion for their drag reduction study on turbulent events in channel flows. Biswas A. (2000) presented fly ash above forty percentage concentration shows non-Newtonian behaviour and viscosity increases promptly with increase in concentration. There are accounts of strong effect of surfactants on rheological behaviour of ash slurry.

Horsely R. R. (1982) suggested that the economic efficiency of the transportation process of the slurry depends on the power requirements for pumping, which successively depends on the concentration, viscosity and yield stress of slurries and proposes the method of design of slurry disposal system.

Jones R. L. and Chandler H. D. (1989) published that fly ash mostly comprises of silica with variable extents of other materials like Aluminium, Iron and alkaline earth materials. The presence of these materials present drag effects on rheology of ash slurry. They also analysed flow behaviour of ash slurry with varying particle sizes and drag reducing chemical agents.

Qi Y., Zakin J.L. and Zhang Y. et al. (2005) investigated on the influence of a cationic surfactant, such as cetyl trimethyl ammonium bromide (CTAB) on the flow behaviour of ash slurry in terms of shear rates, viscosity, temperature and concentration. They found it very effective in reducing friction factors in turbulent flow.

Malik S., Aggarwal L. and Dua A. (2014) performed computational stimulation on ash slurry flow through conduit for survey of pressure drop through straight pipeline and exhibited that pressure drop per 100 meter length across the straight pipeline increases with rise in flow velocity and concentration. They also remarked that slurry with 50% concentration flows at a velocity approx. 41m/sec inside straight pipeline.

2.1 ADVANTAGES OF HCSD DISPOSAL SYSTEM

(i) A lesser amount of power consumption is required. So it is an economic approach.

(ii) A lesser extent of pipe wear occurs.

(iii) It is nearly dry disposal system. So not as much of water consumption is requisite.

(iv) Slurry solidifies, hence restrains ash from flying which ceases air pollution.

(v) In this method, dry stacking occurs which on other hand reduces the required piling land area.

(vi) This method also reduces water pollution, as it is dry kind of disposal system.

2.2 OBJECTIVES

Based on aforementioned literature review, the followings are the current objectives:

(i) To study the geotechnical behaviour of high concentrated ash slurry and determination geoengineering properties.

(ii) Change in behaviour of ash slurry with a course of time.

Chapter 3

3. METHODOLOGY

From Vedanta Aluminium Limited, Jharsuguda plant, disturbed and undisturbed samples were collected; field tests were also conducted.

List of experiments conducted:

1. In-situ density test
2. Variances of bulk density, water content and dry density with time at field
3. Standard proctor test
4. Modified proctor test
5. Specific gravity test
6. Permeability test

3.1 EXPERIMENTAL SETUP & PROCEDURES

3.1.1 In-situ Density Test:

Equipment Used:

i. Core cutters with internal diameter of (a) 10 cm (b) 10.4 cm and effective height of (a) 12.7 cm (b) 13.8 cm.
ii. Soil excavating tool
iii. Oven
iv. Balances
v. Metal containers

Procedure:

Undisturbed fly ash samples were collected from ash pond at Vedanta Aluminium Limited, Jharsuguda with the help of core cutters. Core cutters were greased from inside before it was used and the mass and volume of the empty core cutter was measured and so mass of the core cutter having sample was measured and noted. Some amount of samples were also extracted from core cutter for oven drying for determination of water content. Then the in-situ densities were calculated from the subsequent equations.

$$\gamma = (M_2 - M_1) / V$$

$$\gamma_d = \gamma / [1 + (w/100)]$$

Where,

γ = Bulk density (g/cm^3)

γ_d = Dry density (g/cm^3)

M_1 = Mass of core cutter (g)

M_2 = Mass of core cutter with fly ash (g)

V = volume of the core cutter (cm^3)

w = water content (%)

3.1.2 Variations of Bulk density, Water content & Dry density In a Run of 48 Hours at Different Sites of Ash Pond:

Equipment Used:

i. Core cutter
ii. Soil excavating tool
iii. Oven
iv. Balances
v. Small metal containers

Procedure:

Three different sites of the ash pond at Vedanta Aluminium Ltd., Jharsuguda were chose and named as A, B, C. Empty mass and volume of the core cutter were measured and noted. From each site, samples were taken out with the help of core cutter at a time. Then the mass of core cutter with undisturbed sample were measured for each site. Also some amount of samples from core cutter of each site were taken for further oven drying process for water content determination. Repetition of the above procedure were done after 2, 6, 20, 24, and 48 hours to assess the bulk density, water content and dry density for each time interval for each site. The following formulae govern this test:

$$\gamma = (M_2 - M_1) / V$$

$$\gamma_d = \gamma / [1 + (w/100)]$$

Where,

γ = Bulk density (g/cm^3)

γ_d = Dry density (g/cm^3)

M_1 = Mass of core cutter (g)

M_2 = Mass of core cutter with fly ash (g)

V = volume of the core cutter (cm^3)

w = water content (%)

3.1.3 Standard Proctor Test:

Equipment Used:

i. Cylindrical mould of internal diameter with 10cm and effective height 12.5 cm
ii. Metal hammer of 2.5 kg
iii. Sieve of 20 mm and 4.75 mm
iv. Oven
v. Balances
vi. Metal containers

Procedure:

During the lab test, the mould was attached to a base plate at bottom and to an extension at the top. The mass of the mould only with the base plate was measured. Initially, 2.5 kg of oven dried ash sample was taken and mixed with 10% of water. Then the prepared sample was compacted in 3 equal layers through 25 blows of the hammer from a height of 30.5 cm each. Then the excess ash was cut down by straight edge after removing the top extension. Then the mass of mould with base plate and sample was noted. Some ash sample were collected from the middle of mould for further over drying for water content finding. The above procedure was repeated for more five times with addition of higher percentage of water amount. The following formulae were used for the calculation purpose.

$$\gamma = (M_2 - M_1) / V$$

$$\gamma_d = \gamma / [1 + (w/100)]$$

Where,

γ = Bulk density (g/cm^3)

w = water content (%)

γ_d = Dry density (g/cm^3)

M_1 = Mass of mould with base plate (g)

M_2 = Mass of core mould with base plate and ash sample (g)

V = volume of the mould (cm^3)

3.1.4 Modified Proctor Test

Equipment Used:

i. Cylindrical mould of internal diameter with 10cm and effective height 12.5 cm
ii. Metal hammer of 4.54 kg
iii. Sieve of 20 mm and 4.75 mm
iv. Oven
v. Balances
vi. Metal containers

Procedure:

During the lab test, the mould was attached to a base plate at bottom and to an extension at the top. The mass of the mould only with the base plate was measured. Initially, 2.5 kg of oven dried ash sample was taken and mixed with 10% of water. Then the prepared sample was compacted in 5 equal layers through 25 blows of the hammer from a height of 45.7 cm each. Then the excess ash was cut down by straight edge after removing the top extension. Then the mass of mould with base plate and sample was noted. Some ash sample were collected from the middle of mould for further over drying for water content finding. The above procedure was repeated for more five times with addition of higher percentage of water amount. In this modified version, only the compact energy was increased. The following formulae were used for the calculation purpose.

$$\gamma = (M_2 - M_1) / V$$

$$\gamma_d = \gamma / [1 + (w/100)]$$

Where,

γ = Bulk density (g/cm^3)

γ_d = Dry density (g/cm^3)

w = water content (%)

V = volume of the mould (cm^3)

M_1 = Mass of mould with base plate (g)

M_2 = Mass of core mould with base plate and ash sample (g)

3.1.5 Specific Gravity Test

Specific gravity is specified as the ratio of the unit weight of a given sample to the unit weight of the water at a specific temperature.

Equipment Used:

i. Density bottles
ii. Vacuum desiccator
iii. Oven
iv. Balances

Procedure:

4 numbers of density bottles were dried in oven and cooled in desiccator. 50 g of oven dried ash sample was taken and weighed with the bottle. Then, air-free distilled was added to the bottle and the bottle with dry ash and water was kept in vacuum desiccator for 1 hour. After bringing out from the desiccator, the mass was measured and noted. Then the bottle was filled only with air-free distilled water and cleaned thoroughly from outside for no mark of water drops and weighed. This same process was followed for other three density bottles too. Here, the specific gravity of collected fly ash was calculated by following formula:

$$G = (M_2 - M_1) / (M_4 - M_1) - (M_3 - M_2)$$

Where,

M_1 = Mass of density bottle (g)

M_2 = Mass of density bottle + dry ash

M_3 = Mass of density bottle + ash + water

M_4 = Mass of bottle + water

3.1.6 Permeability Test (Constant Head)

Permeability announces the ease with which water can flow through a given sample (fly ash). The knowledge of permeability is vital in clarifications of many engineering complications involving flow of water through soil or ash such as:

a) Assessing seepage through the body of earth dam
b) Figuring losses from canal
c) Computing seepage rate from waste storage facility

Equipment Used:

i. Permeameter mould including drainage base and drainage cap
ii. Water reservoir for water supply
iii. Graduated flask
iv. Stop watch

Procedure:

Undisturbed ash sample was filled in permeameter and placed centrally over the porous disc. The drainage base was fixed to the mould. After compacting little with tampered rod, porous stones were kept above it. Then the top inlet was connected to water supply and the bottom outlet was opened when steady state of flow was established. The quantity of flow for a precise time was collected in graduated flask and measured. This process was repeated for another three times. The following formula was used for calculation of coefficient of permeability.

$$k = QL / Aht$$

Where,

k = Coefficient of permeability (cm/sec)

t = Time of discharge

Q = Volume of discharge (cm^3)

L = length of specimen (cm)

A = Cross-sectional area of permeameter (cm^2)

h = Hydraulic head difference (cm)

Chapter 4

4. RESULTS AND DISCUSSIONS

4.1 IN-SITU DENSITY TEST

The in-situ bulk density of ash slurry of the field study was found out to be 1.7 g/cm^3 and in-situ dry density was determined to be 1.4 g/cm^3 from four observations given below (Table-1).

Table 1: In-situ density test

Sl. No.	Mass of fly ash (g)	In-situ Bulk density γ (g/cm^3)	Water content w (%)	In-situ Dry density γ_d (g/cm^3)
1	1553	1.556	16.32	1.337
2	1578	1.581	15.39	1.37
3	1837	1.559	16.47	1.338
4	1864	1.582	14.72	1.379

4.2 VARIATIONS OF BULK DENSITY, WATER CONTENT & DRY DENSITY IN A RUN OF 48 HOURS AT DIFFERENT SITES OF ASH POND

From the field tests at different sites, it was observed that the bulk density remained same for each site throughout the time. The water content and dry density also didn't vary more for each site. It can be observed from the succeeding observations (Table-2) and comparative graphs stated below.

Table 2: Bulk density, Water content and Dry density of site-A,B,C at different time intervals

Site, Hour	Bulk density γ (gm/cm^3)	Water content w %	Dry density γ_d (gm/cm^3)
A, 0 hour	1.59	19.11	1.335
B	1.71	24.87	1.369
C	1.53	16.56	1.313
A, 2 hour	1.58	19.08	1.327
B	1.68	24.15	1.353
C	1.52	16.22	1.308
A, 6 hour	1.58	18.87	1.329
B	1.69	24.7	1.355
C	1.53	16.47	1.314
A, 20 hour	1.59	18.68	1.34
B	1.68	24.32	1.351
C	1.51	15.83	1.304
A, 24 hour	1.56	18.71	1.314
B	1.67	24.46	1.342
C	1.53	15.92	1.32
A, 48 hour	1.57	18.03	1.33
B	1.7	23.86	1.373
C	1.52	15.97	1.311

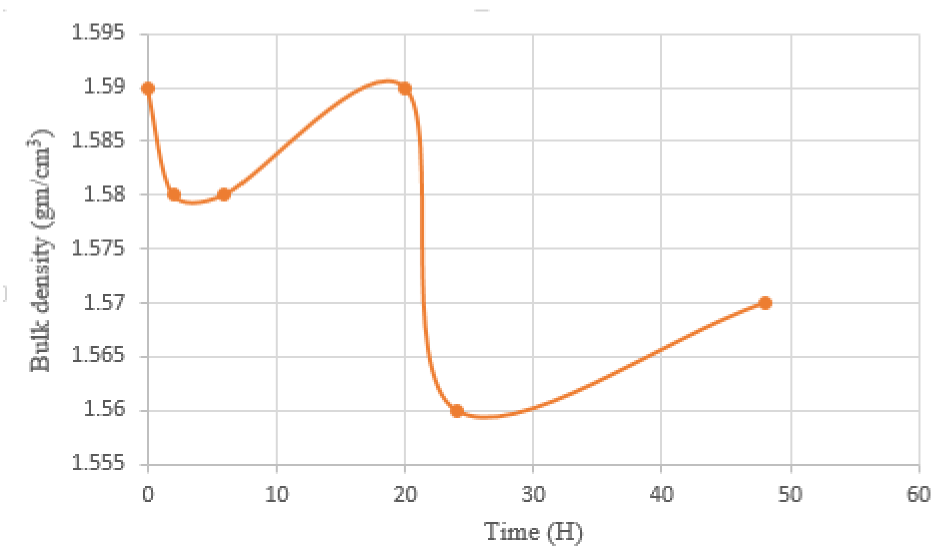

Figure 1(a): Bulk density vs Time for site 'A'

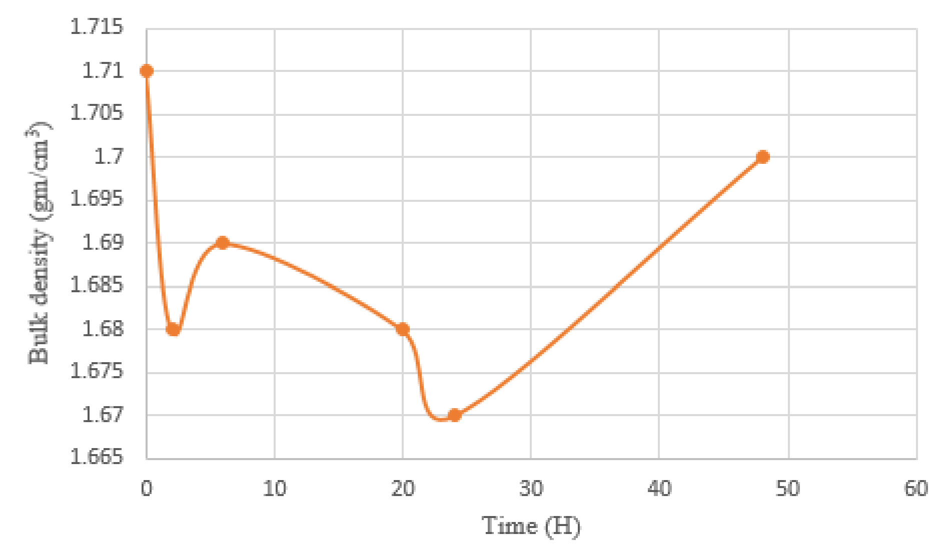

Figure 1(b): Bulk density vs Time for site 'B'

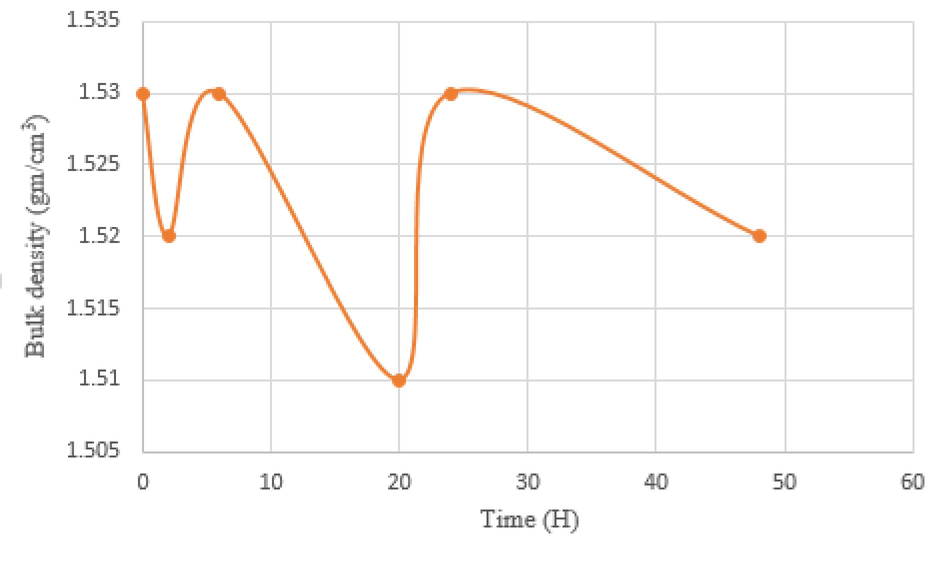

Figure 1(c): Bulk density vs Time for site 'C'

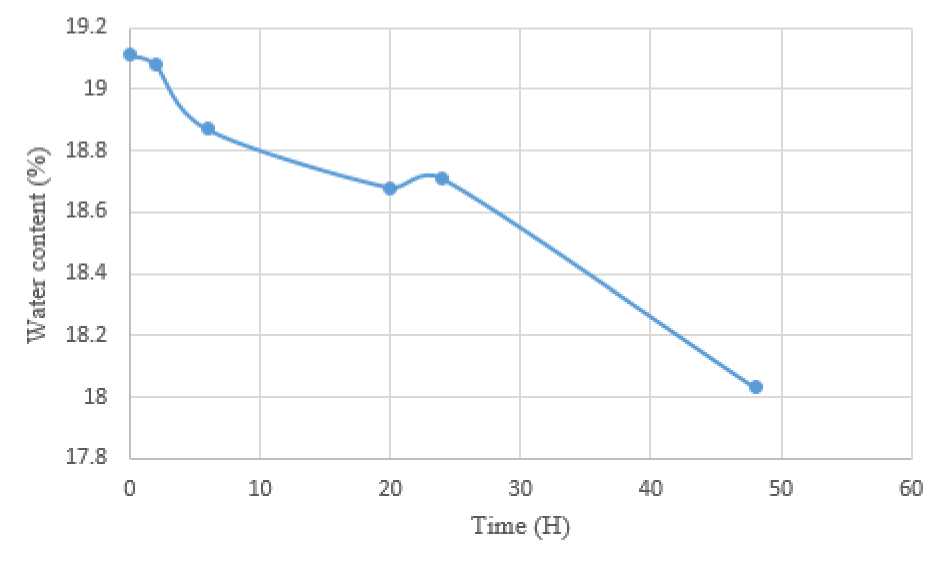

Figure 1(d): Water content vs Time for site 'A'

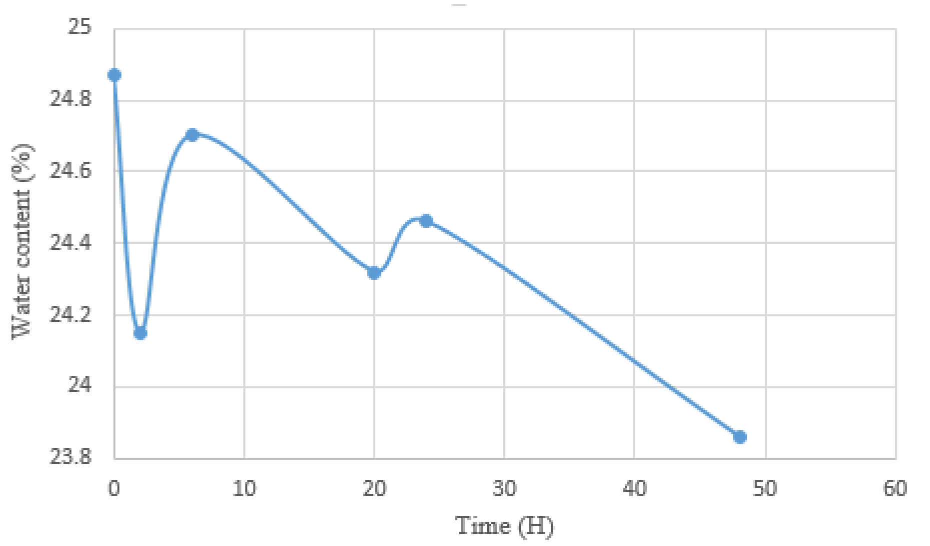

Figure 1(e): Water content vs Time for site 'B'

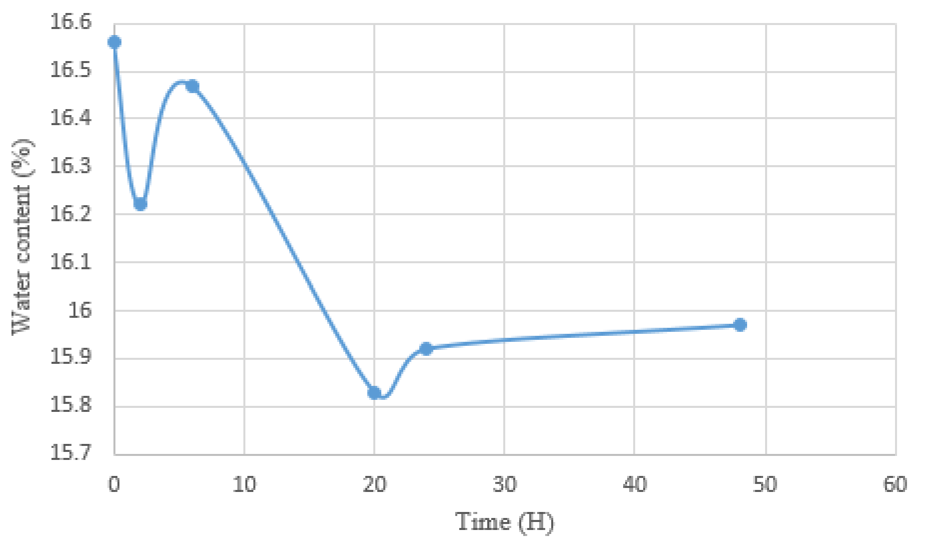

Figure 1(f): Water content vs Time for site 'C'

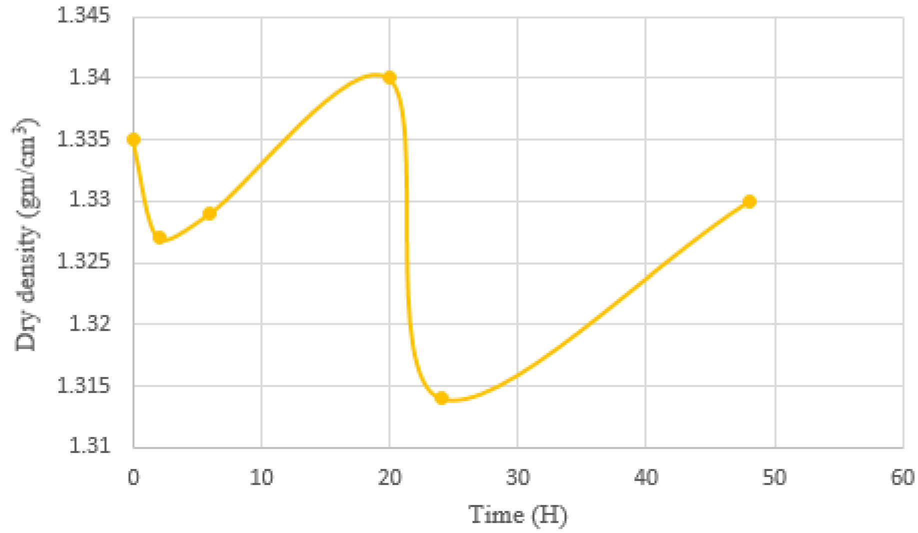

Figure 1(g): Dry density vs Time for site 'A'

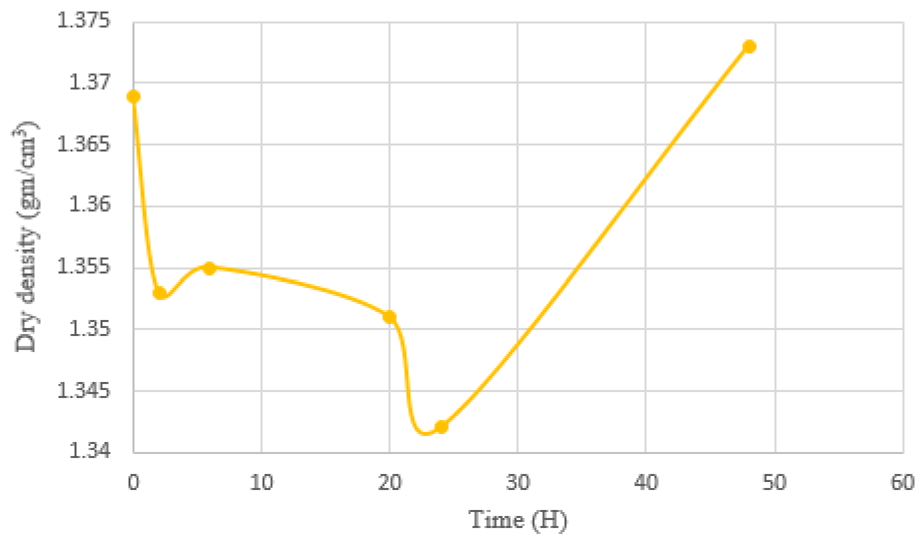

Figure 1(h): Dry density vs Time for site 'B'

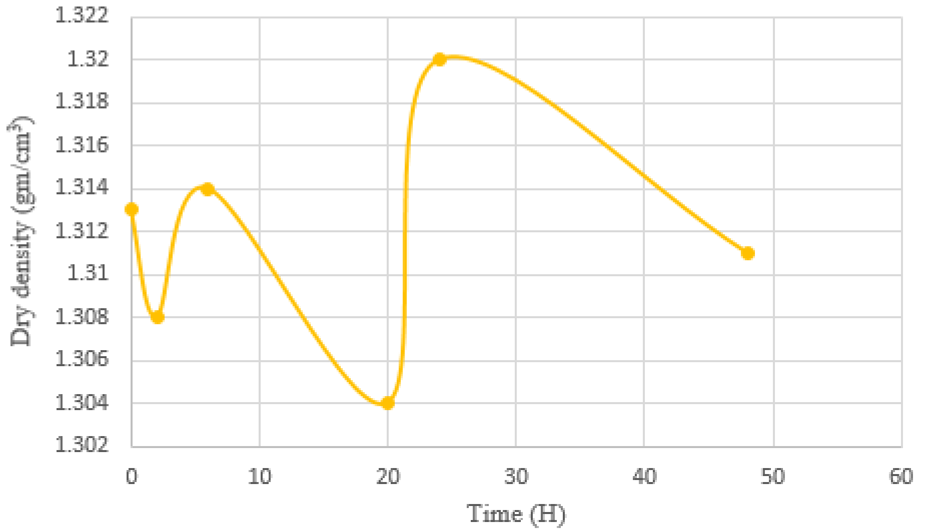

Figure 1(i): Dry density vs Time for site 'C'

4.3 STANDARD PROCTOR TEST

The maximum dry density (M.D.D) and corresponding optimum moisture content (OMC) of the collected ash sample was determined to be 1.367 g/cm^3 and 20.13% respectively. The observations and graphs are shown below.

Table 3: Standard Proctor test

Sl. No.	Wt. of ash (g)	Bulk density γ(g/cm^3)	Water content w (%)	Dry density γ_d (g/cm^3)
1	1530	1.597	17.81	1.355
2	1538	1.605	18.27	1.357
3	1551	1.618	18.74	1.362
4	1559	1.627	19.29	1.363
5	1572	1.64	20.13	1.365
6	1541	1.608	20.47	1.334

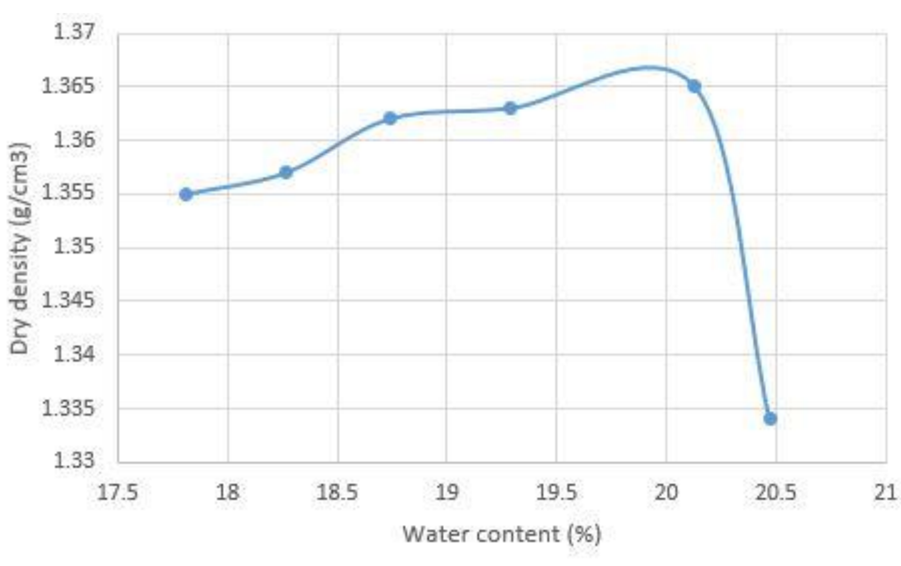

Figure 2: Dry density vs Water content for Standard Proctor test

4.4 MODIFIED PROCTOR TEST

The maximum dry density (M.D.D) and corresponding optimum moisture content (OMC) of the collected ash sample for this test, was found out 1.464 g/cm^3 and 18.19% respectively. The observations and graphs are shown below.

Table 4: Modified Proctor test

Sl. No.	Wt. of ash (g)	Bulk density γ(g/cm^3)	Water content w (%)	Dry density γ_d (g/cm^3)
1	1547	1.64	16.44	1.41
2	1592	1.69	17.38	1.44
3	1628	1.73	18.19	1.464
4	1617	1.694	19.67	1.415
5	1603	1.7	21.82	1.395
6	1613	1.711	23.99	1.37

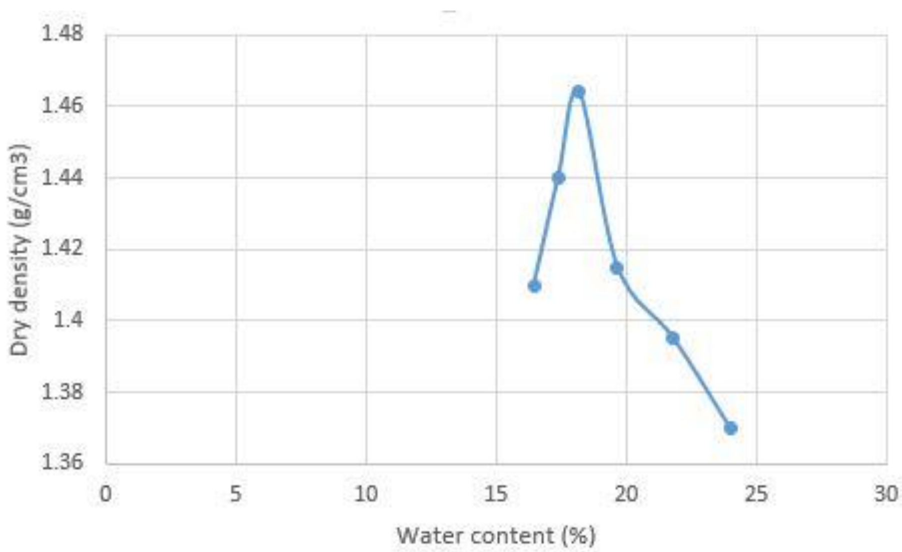

Figure 3: Dry density vs Water content for Modified Proctor test

4.5 SPECIFIC GRAVITY TEST

The specific gravity of the collected ash sample was found to be 2.14. The observations were given below (Table-5).

Table 5: Specific Gravity test

Test No.	M_1 (g)	M_2 (g)	M_3 (g)	M_4 (g)	Specific gravity G
1	104.58	148.07	373.79	351.64	2.03
2	108.52	155.03	383.06	358.41	2.13
3	97.56	146.32	371.71	345.68	2.15
4	111.69	157.88	385.83	360.27	2.23

4.6 PERMEABILITY TEST (CONSTANT HEAD)

The permeability of the collected ash sample from ash pond was detected to be $1.261 x 10^{-4}$ cm/sec. That can be observed from the observations (Table-6) stated below.

Table 6: Permeability test

Test No.	Length of specimen L (cm)	Area of permeameter A (cm^2)	Hydraulic gradient h (cm)	Time of discharge t (seconds)	Volume of discharge Q (cm^3)	Coefficient of Permeability k (cm/sec)
1	15	79	204	600	79.61	$1.235x10^{-4}$
2	15	79	199	600	80.25	$1.276 x10^{-4}$
3	15	79	192	600	75.92	$1.251 x10^{-4}$
4	15	79	183	600	74.12	$1.282 x10^{-4}$

Chapter 5

5. CONCLUSIONS

i. From the limited tests conducted in the laboratory on the samples collected from the specific sites over the specified period of time, it is observed that the dry density of pond ash at different locations of ash-pond remains same and is of the order of 1.4 g/cc. There is no gain in dry density over the time the ash settles in the pond.

ii. The permeability of the high concentrated settled ash slurry collected from ash pond is of the order of 1.3×10^{-4} cm/sec, which is almost same for most lean slurry disposal system. Therefore, there is no much gain in impermeability with high concentrated slurry system.

iii. From the proctor tests, it is observed that more compactive effort over the pond ash collected from HCSD system results in more MDD and less optimum moisture content that indicating suitable for embankment construction.

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